The Smallest Terrestrial Planet Seen in the Light of Dawn

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The Dawn Mission

- Top level objective:
  - Explore backward in time to understand the origin of the solar system
- Approach
  - Orbit and map two of the oldest intact bodies in the solar system, the main belt asteroids Vesta and Ceres
  - Use ion propulsion to provide needed ΔV
  - Carry Camera, Vis and IR Mapping Spectrometer, Gamma Ray and Neutron Spectrometer and use Radiometric tracking for gravity studies
- History
  - Selected for development in 2001
  - Launched in September 2007
  - Arrived at Vesta in July 2011
  - Left Vesta in September 2012
  - Will arrive at Ceres in March 2015

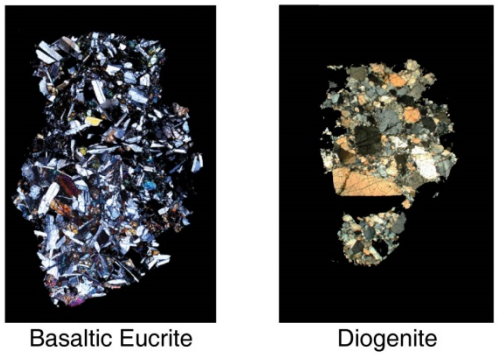
Dawn Spacecraft at Earth

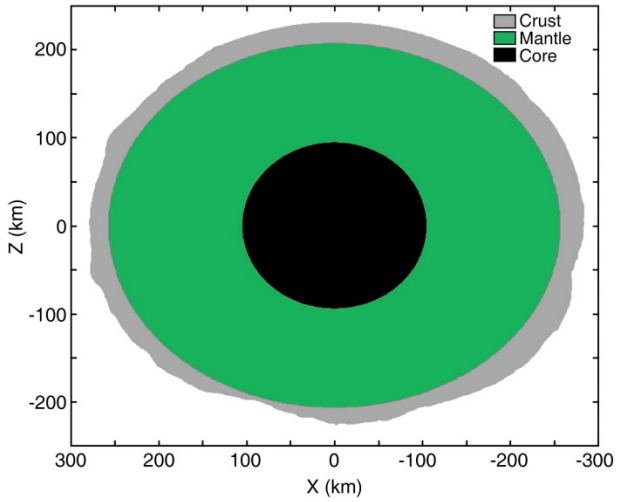
What Did We Know About Vesta Then?

- Mass from its effects on Mars position
- Size from stellar occultation, HST and adaptive optics observations
- Composition of surface from HED meteorites
- Composition of surface from reflectance spectrum
- When Vesta formed
- Rough shape of Vesta

From this we formed a simplistic model of Vesta

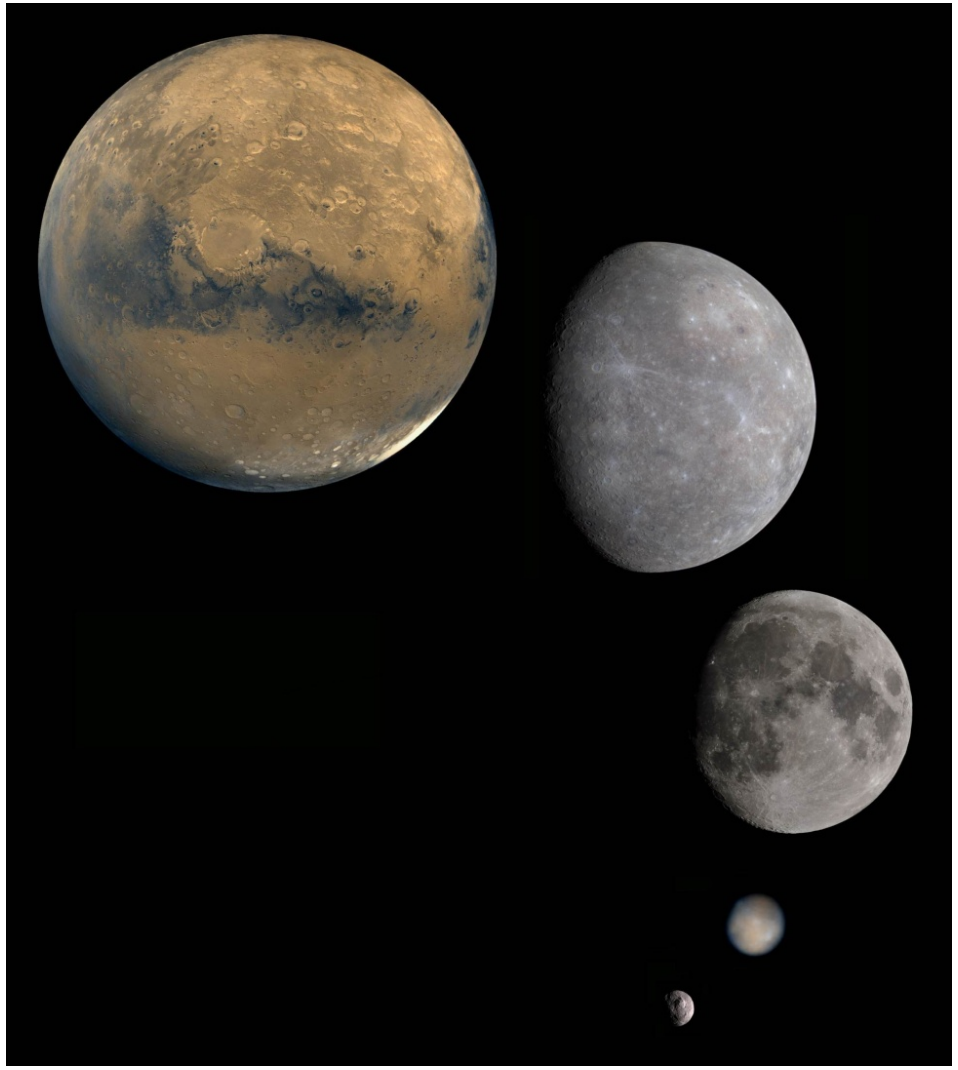
- Iron core of about 100 km
- Olivine mantle
- Eucritic/diogenitic crust
- Currently inactive, dry body shaped by impact processes





The Smallest Terrestrial Planet

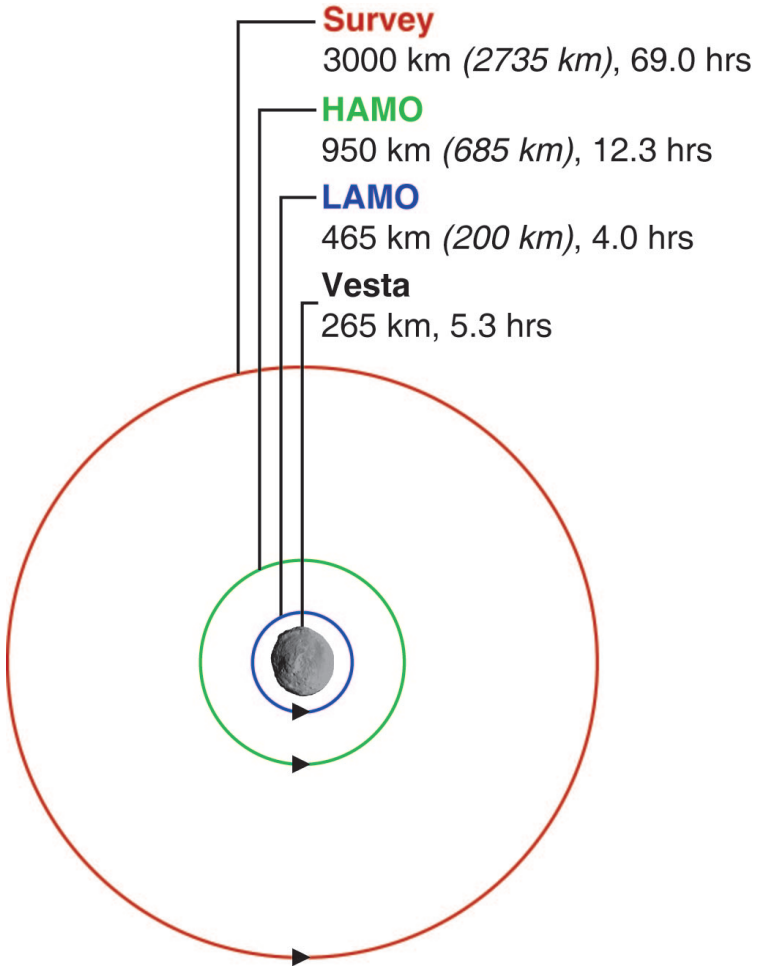
- While Vesta is much smaller than any terrestrial body, it has features and processes reminiscent of them.
- Some terrain on Vesta resembles that on Mars and that on Mercury.
- Relief of the surface relative to its radius is greater on Vesta.
- Vesta has an older surface in general.
- Can we see past the late heavy bombardment on Vesta?



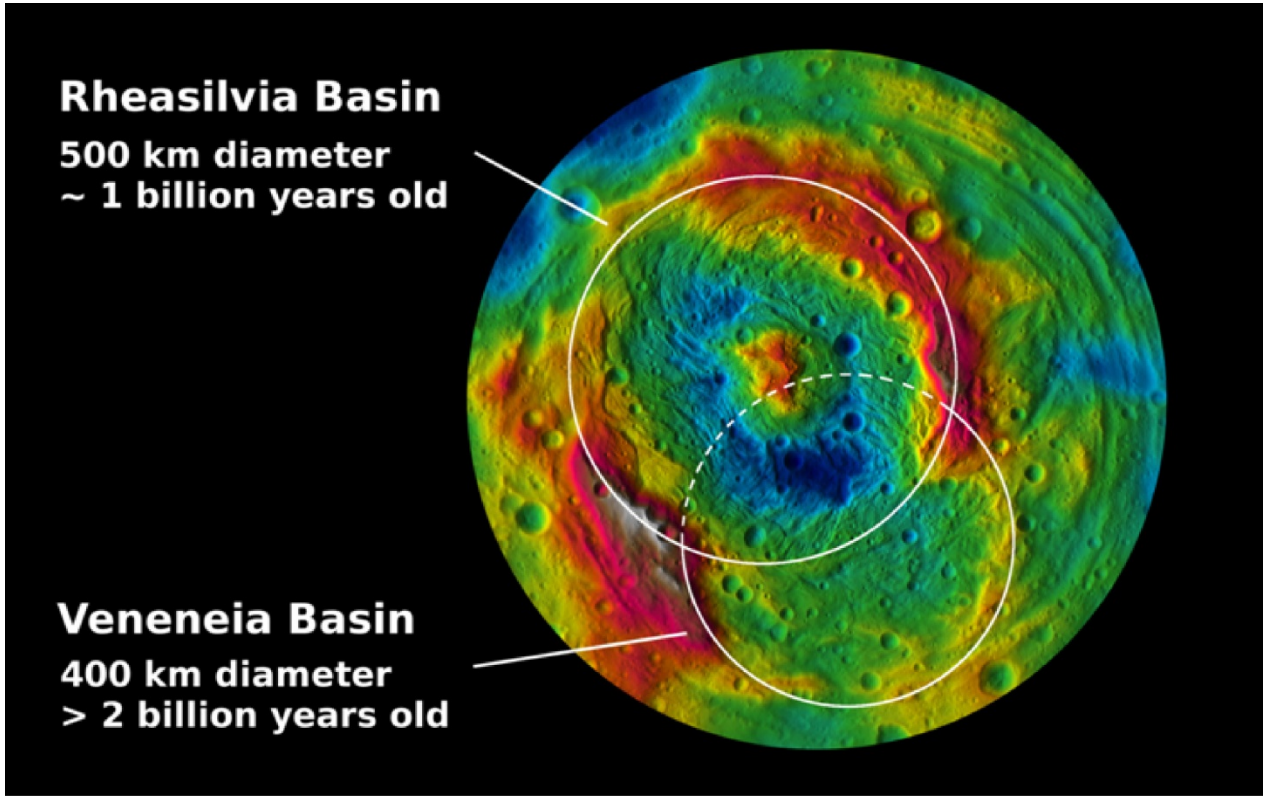
Vesta, Ceres, the Moon, Mercury, and Mars

How Did We Obtain the Data?

- Since we know so little about our targets initially, we proceed with a series of orbits of decreasing radius.
  - The first orbit is "Survey" in which we obtain low-resolution imagery of the entire surface, gravity data to enable us to navigate accurately and complete coverage of the surface with the VIR spectrometer.
  - In the high-altitude mapping orbit (HAMO), we obtain complete surface coverage in all camera filters and images for topography, and higher resolution VIR data.
  - In the low-altitude mapping orbit (LAMO), we obtain gamma ray and neutron data, gravity measurements and highest but incomplete coverage with the camera and VIR.
  - Before leaving Vesta, we obtained more data from a second HAMO phase to take advantage of improved solar illumination conditions over the northern hemisphere.



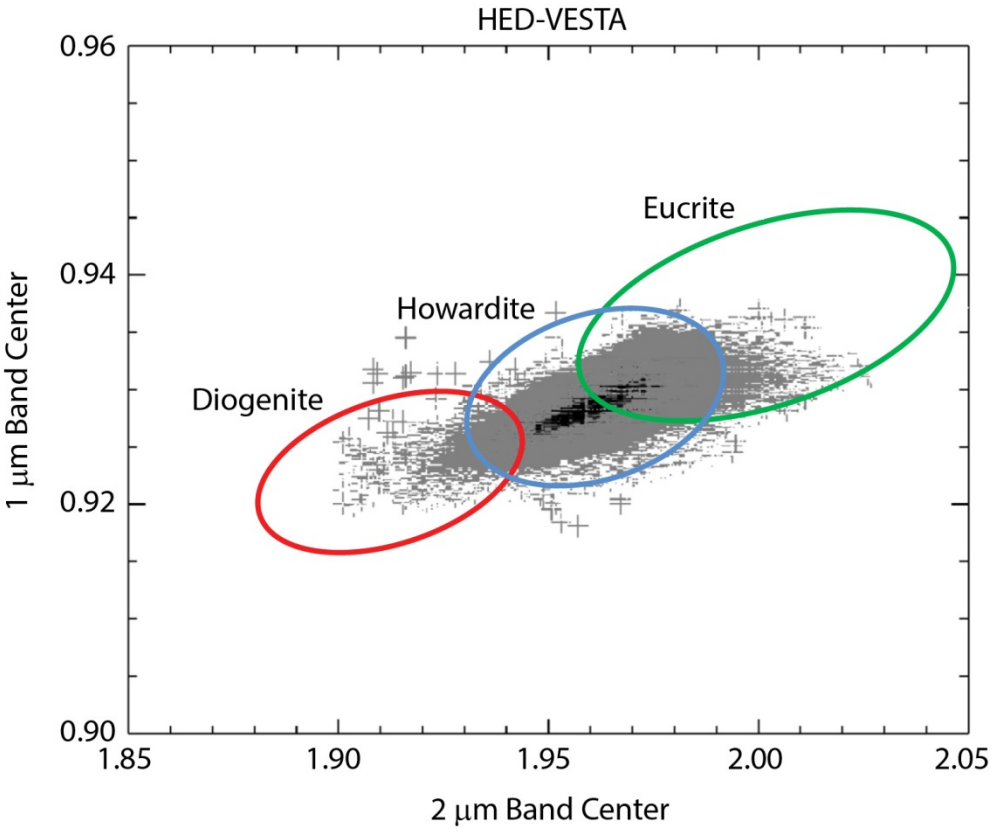
Vesta has Steep Topography



- The strength of the vestan crust is similar to that on all the terrestrial planets, yet because of its small mass, gravitational stresses are much weaker. Hence, the vestan surface supports steep topography. Slopes are very important on vestan geomorphology.
- We also found two ancient basins in Vesta's southern hemisphere.

Basaltic Surface of Diogenite, Howardite, and Eucrite

- Both VIR and GRaND showed that the composition of the surface material was consistent with the HED meteorites.
- So on the surface, Vesta was found to be as expected.
- The paradigm to which geochemistry had led us on the origin of the solar system seemed safe.
- Yet there were surprises.



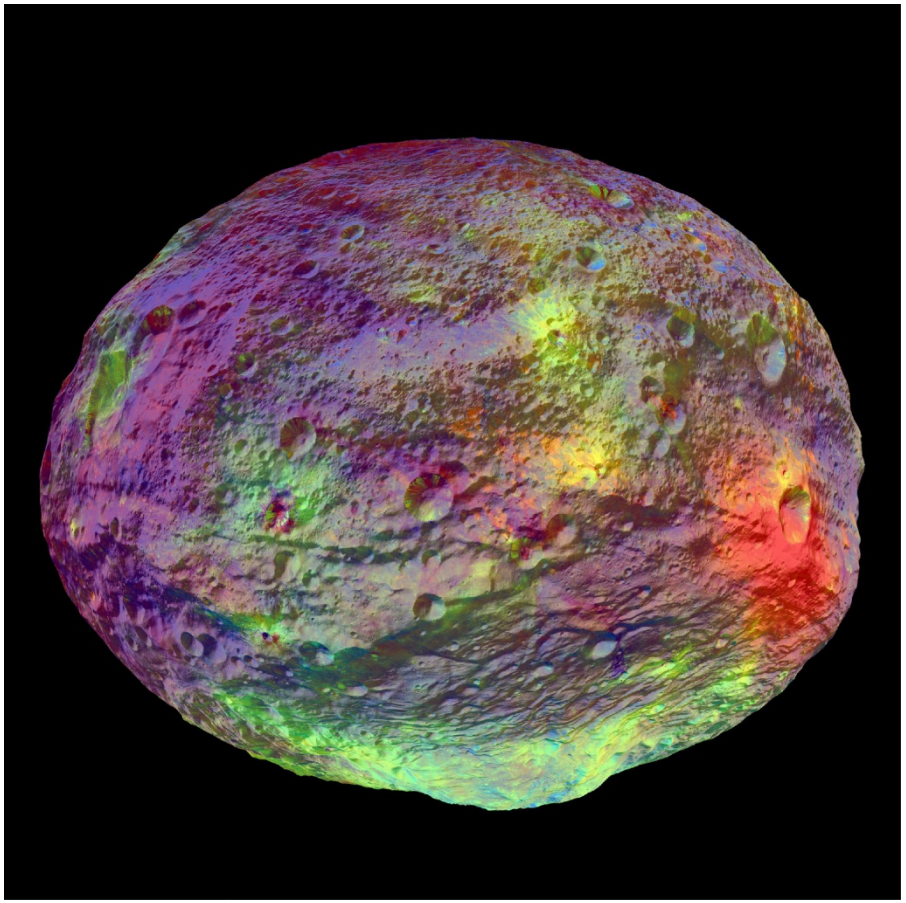
(DeSanctis et al., 2012)

The Tectonics Evident on the Surface Were a Surprise

- While Klaus Keil had told us that Vesta was the littlest terrestrial planet, seeing it was a surprise.
- This was an asteroid unlike anything we had seen before.
- It had mountains and valleys. It had graben circling the planet.
- It had swirls on the floor of Rheasilvia, the younger southern basin associated with coriolis forces.
- We were surprised by the placement of the snowman craters and their unique ejecta blanket.

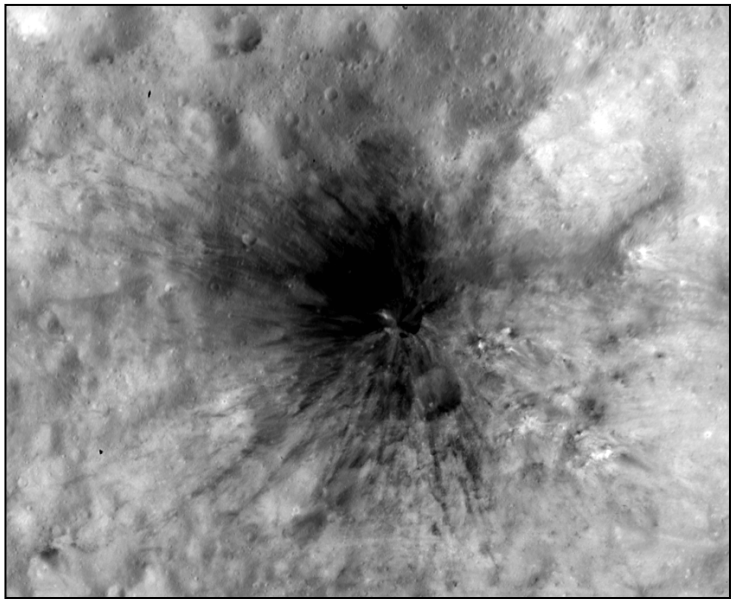
The Diversity of the Surface Was a Surprise

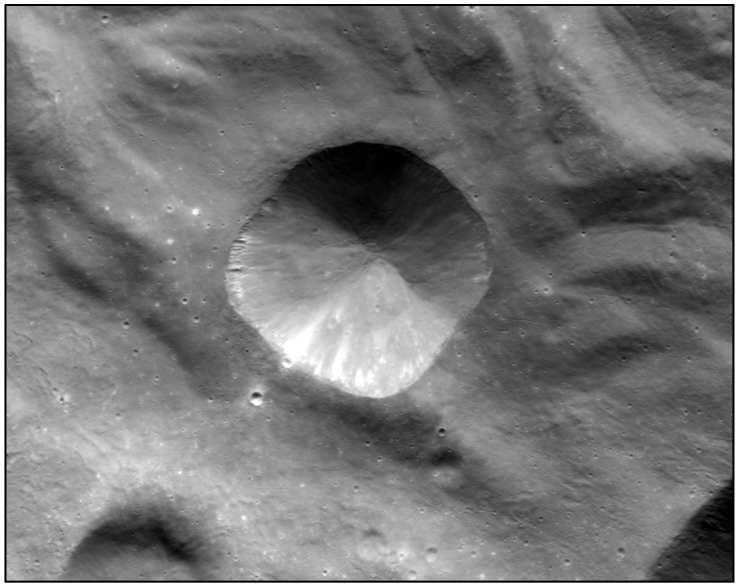
- Vesta is not a uniform slab of rock.
- Its varied surface speaks of internal diverse internal processes.
- The surface is varied in black and white as well as color. It has dark streaks in crater walls and dark rayed craters.
- There are long subsurface black linea on Vesta overlain by bright material that have been pierced by craters.



Bright and Dark Material on the Surface

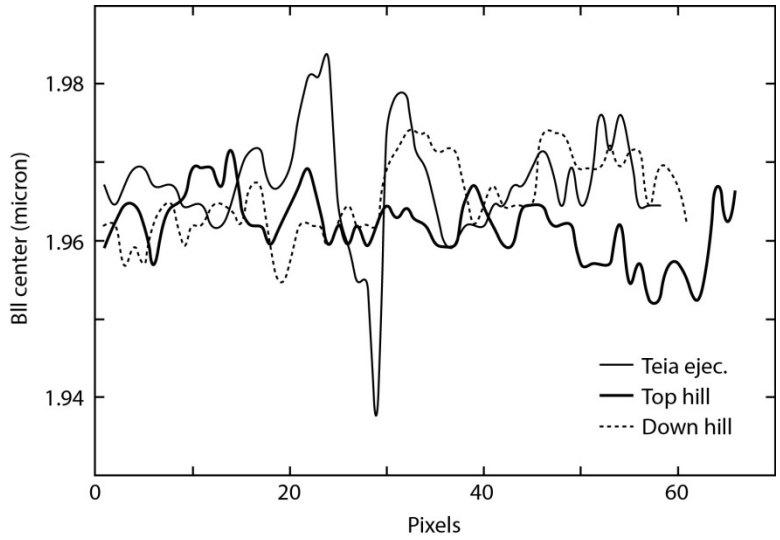
- Often as on the crater on the top right, craters have dark rays.
- These appear at times to be due to the impact of the crater forming object into buried black material.
- But the rays could also be produced by the delivery of carbonaceous materials in the impactor itself.
- The bright materials on the bottom right appear to be materials originally formed on Vesta with minimal mixing of dark materials nor space weathering.
- "The range of albedos is among the largest observed on solar system rocky bodies." (McCord et al., Nature, 2012)

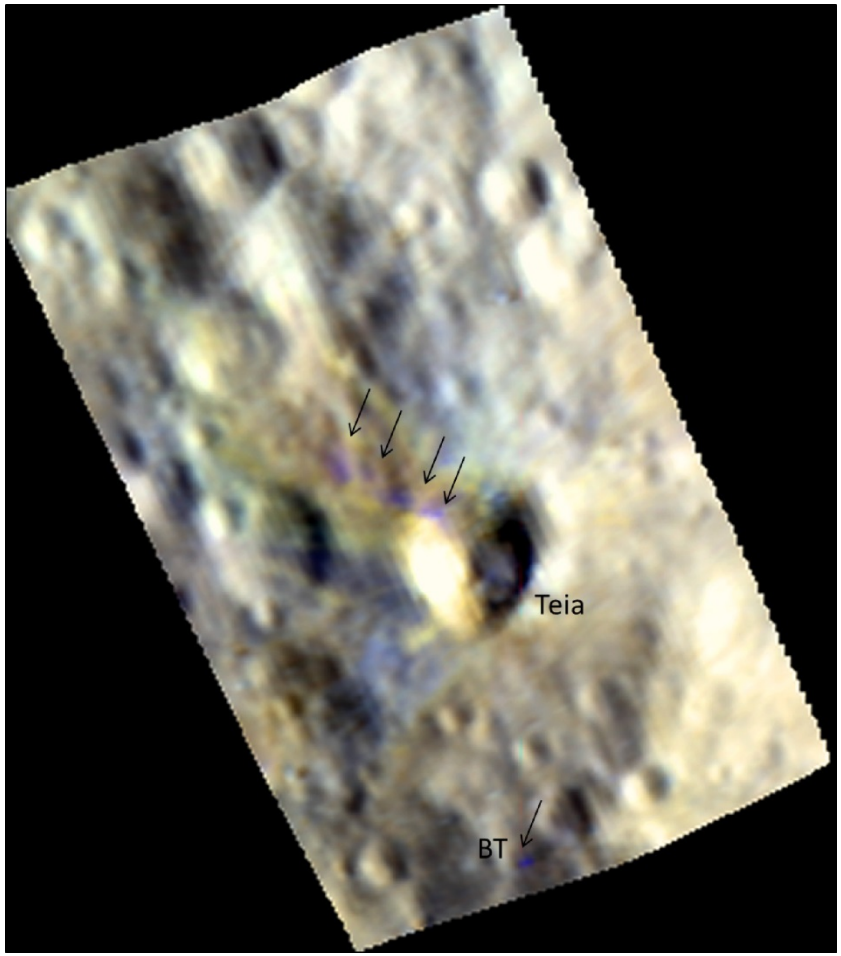




Volcanism was Predicted to Have Been Once Present

- We did not expect to see evidence remaining so long after Vesta formed.
- Brumalia Tholus may provide evidence of ancient volcanism.
- Material coming out of Teia crater is much different than its surroundings.
- Did the crater penetrate an intrusive body?

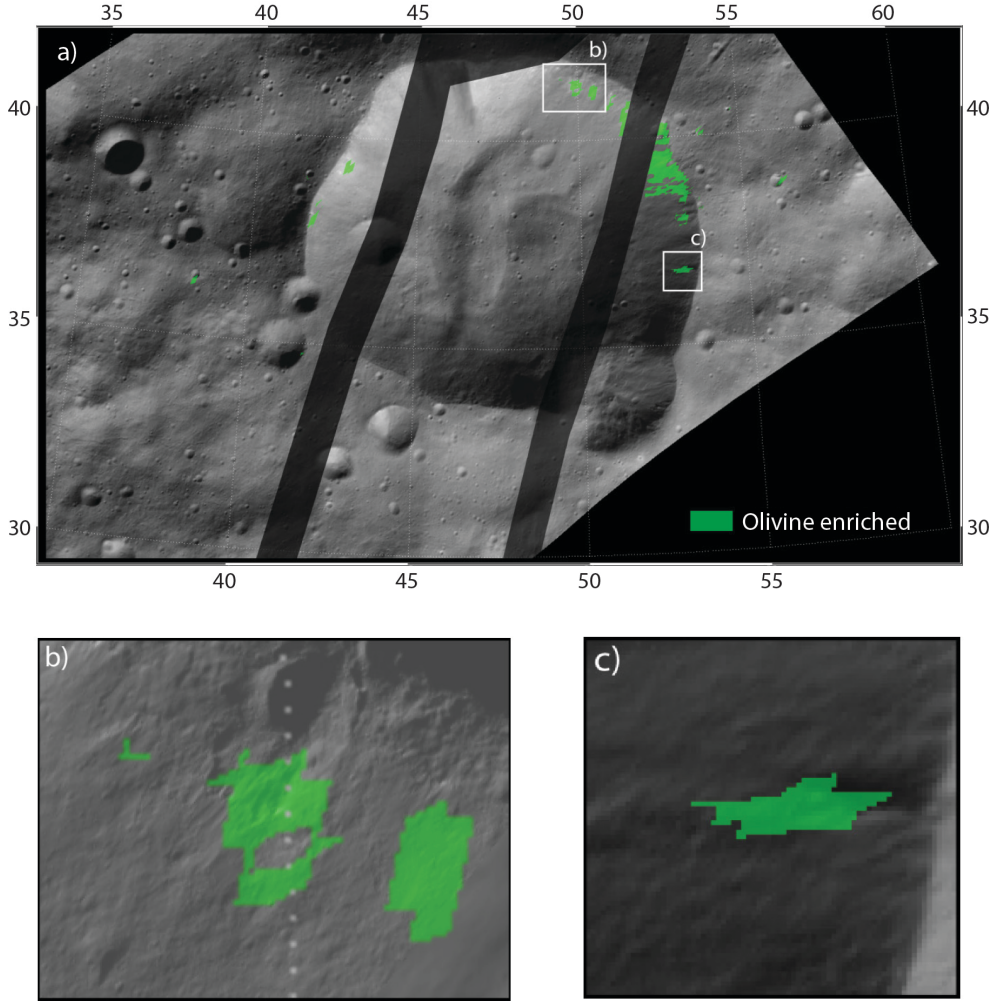




(DeSanctis et al., 2014)

Paradigm Lost: The Magma Ocean

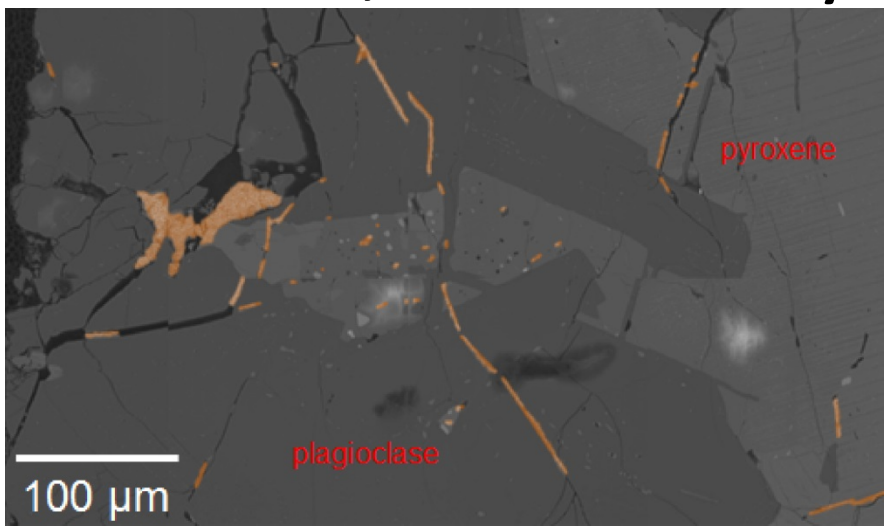
- Prior to arrival, we thought that Vesta had an iron core, an olivine mantle, and a eucritic-diogenitic crust.
- Rheasilvia should have excavated down to the olivine, but Rheasilvia's floor was diogenitic.
- Eventually patches of olivine were found, but this finding is not consistent with the magma ocean paradigm.
- Were there plutons? Magma chambers?



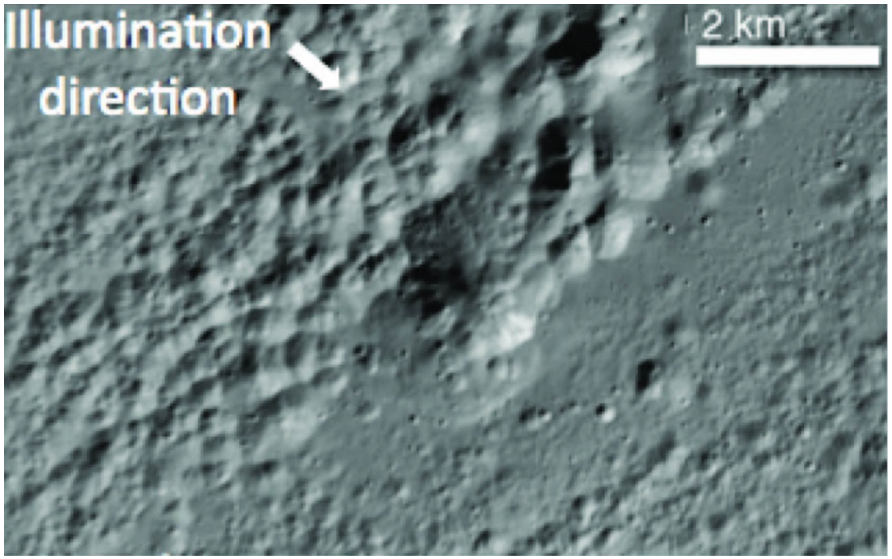
(Ruesch et al., 2014)

Big Paradigm Shift: Vesta is Wet, Even Today

- There is evidence for water in the meteorite record
  - A quartz veinlet
  - Apatite
  - Carbonaceous inclusions
- In crater floors, there are pits as if material devolatized.
- Was there standing water on Vesta?
- What other evidence could have survived?

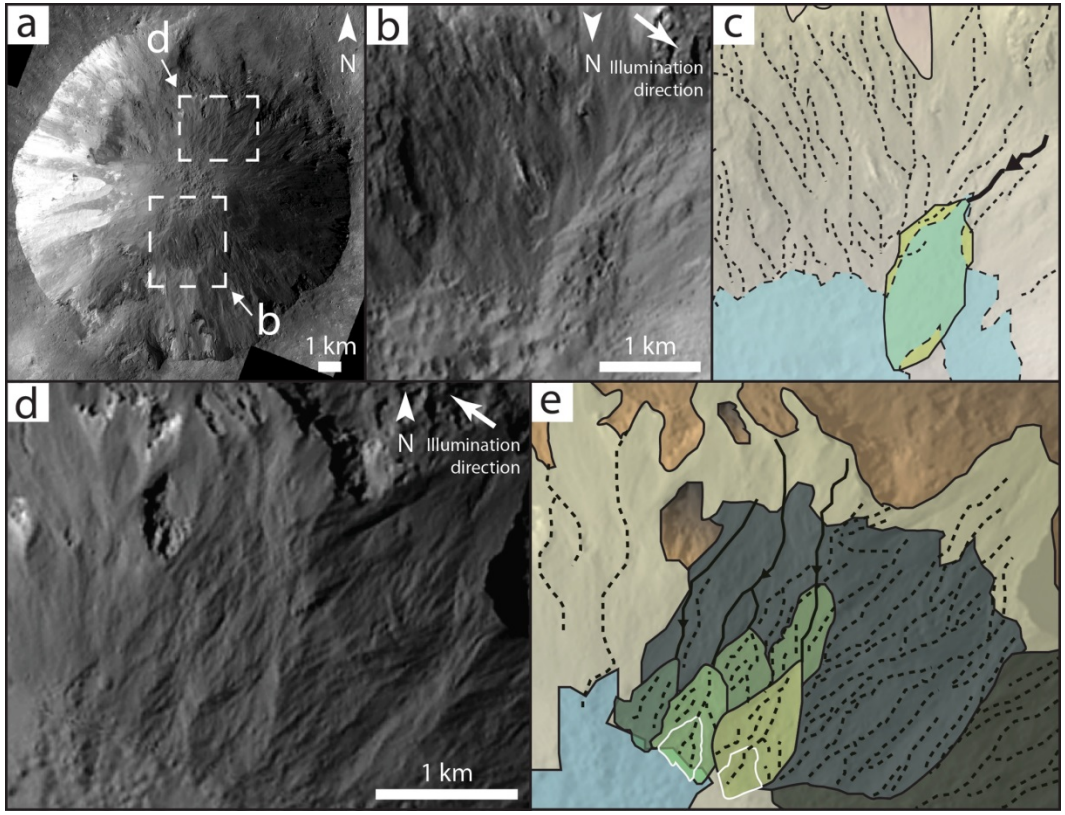


(Sarafian et al., 2013)



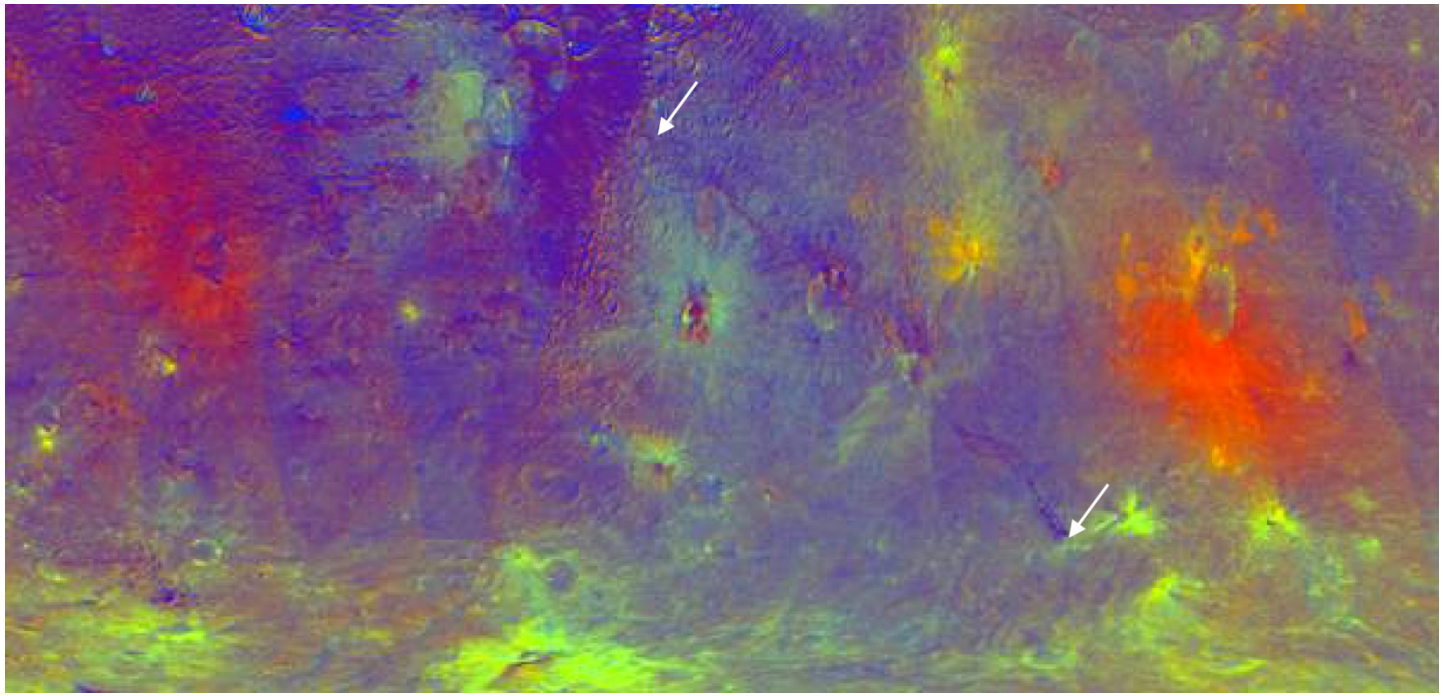
(Denevi et al., 2012)

Curvilinear Gullies in Crater Walls: Water Once Flowed Transiently



- Gullies are seen in crater walls that curve and interconnect like terrestrial streams.
- These morphologies indicate they are not due to flow of dry material.
- Marcia crater has extensive curvilinear gullies. It has pits in the crater floor. It has pits in its ejecta blanket. Its ejecta blanket is OH-rich.

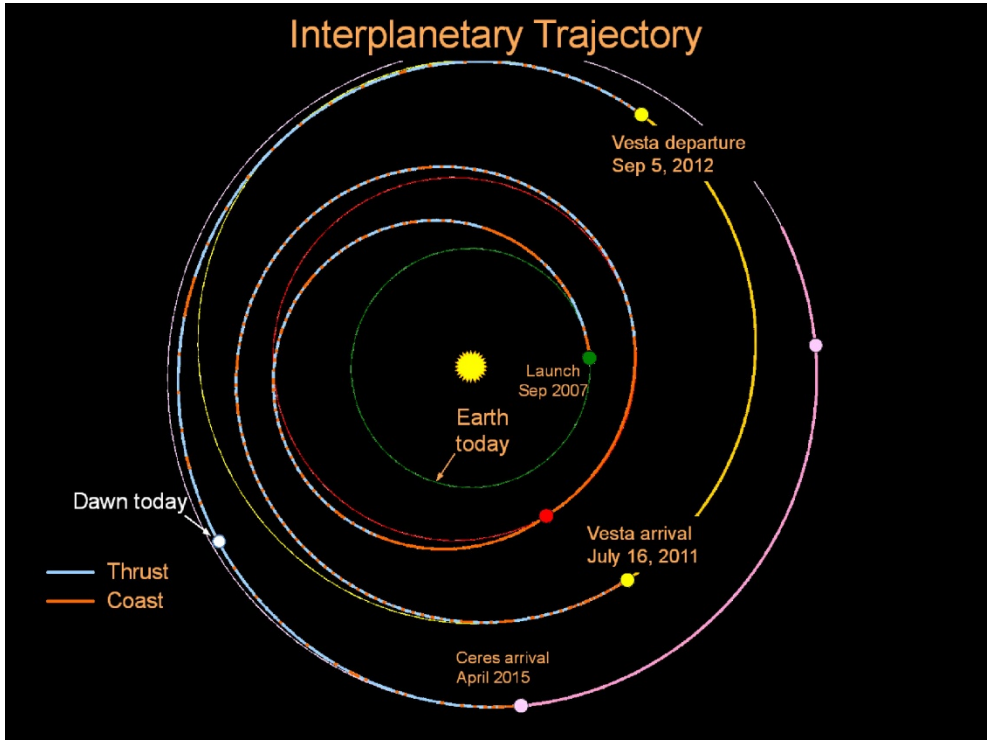
The Ribbon: Starting at Calpurnia and Stretching Across the Landscape



- Marcia is about 150 Ma in age, and Calpurnia maybe 800 Ma.
- A ribbon on material appears to stretch from Calpurnia. It cannot be as old as Vesta.
- Could water be released from subsurface ice in some regions of Vesta's surface?
- Could there have been transient atmospheres on Vesta?
- The Dawn team is puzzling over the geomorphology around Marcia.

Where Is Dawn Now?

- Dawn has left Vesta and set sail for Ceres.
- We expect to arrive next year in late March.
- We are expecting a much wetter planet than Vesta.
  - Its density is much less than that of Vesta.
  - Plumes have been reported arising from its surface.
- We are planning the same exploration strategy as we used at Vesta.



Conclusions

- Vesta is a tiny planet. It clearly was undergoing a transformation from accreted dust to a differentiated world with the processes we find on the larger planets.
- It is far from a homogeneous blob. It is a world with diversity and character. It has a very interesting surface and a structured interior.
- Water has played and may still play an important role on Vesta. Transient atmospheres and running water appear to have been present.
- Vesta is bright and appears fresh. What has led to this high albedo?
- Vesta certainly deserves the title of the "littlest terrestrial planet." It is intact and it supports many of the processes that we associate with a terrestrial planet.

The Smithsonian Award for Current Achievement

- The Dawn mission has succeeded through the efforts of many individuals, companies, and scientific and industrial institutes.
- We are very grateful for their efforts.
- This year these efforts were recognized by the Smithsonian National Air and Space Museum award for Current Achievement.

The Dawn flight team receiving the Smithsonian award on March 26, 2014.

Any Questions?